INFORMATION

Rare-earth elements in deep-sea marine mineral deposits

February 2026

Rare earths are important for the high-tech sector as well as the energy and mobility transition. They could be extracted from marine mineral deposits in the future.

In the light of the current geopolitical challenges of diversifying and securing the supply of raw materials for Germany and Europe, the KDM Strategy Group Marine Mineral Resources provides information on the occurrence of rare earths in marine mineral resources of the deep-sea.

1. Introduction

The rare earths group comprises 15 economically relevant elements that usually occur together in mineral deposits due to their similar geochemical properties. The most important applications worldwide include permanent magnets (29% in 2020), chemical and automotive catalysts (20%), polishing agents (14%), iron and steel alloys (9%), glass (8%), and other applications, for example in medical technology (Elsner et al., 2025). The rare earths that are particularly important for new technologies (wind power, e-mobility) are neodymium (Nd), praseodymium (Pr), terbium (Tb), and dysprosium (Dy).

Most land deposits of rare earths are found in certain igneous rocks (especially carbonatites), in mechanically enriched sedimentary accumulations (known as heavy mineral placers), and in chemically enriched clays (ion adsorption clays). Rare earths are mined in 18 countries, with China dominating with a 69% share of total production (as of 2024). In addition, China has a 93% share of the global market for the processing and further refinement of high-purity compounds. The expertise required for complex and capital-intensive refinement is not widely available and, in the case of heavy rare earths (e.g., terbium and dysprosium), currently only exists in China and France. This means that rare earths are not only key resources in terms of raw materials, but also in terms of security and industrial policy.

Problematic aspects of the metallurgical processing of rare earths are strong environmental pollution caused by the chemicals used as well as the release of heavy metals and the accumulation of radioactive elements (uranium, thorium). The recycling rate of rare earths (end-of-life recycling input rate) is cur-

rently less than 1% in the EU and therefore contributes only marginally to the supply. The German economy consumes approximately 5,000 tons of rare-earth compounds annually which are used primarily for catalyst production. Most of them are imported from China. Permanent magnets, e.g. for wind turbines, are imported directly from China. The overall market is currently characterized by a slight oversupply, but due to geopolitical tensions, at least outside China, prices are rising. This trend facilitates the development of new mining projects.

2. Rare earths in marine mineral deposits

Marine mineral resources include manganese nodules, ferromanganese crusts, massive sulfides, rare-earth-rich deep-sea mud, and phosphorites. However, only ferromanganese crusts, phosphorites (Figure 1), and deep-sea mud are of interest as sources, as only they can contain commercially viable quantities of rare earths. Typical total contents range from approx. 0.05% for phosphorites to 0.5% for ferromanganese crusts (Hein et al., 2013, 2016). Mineable grades of terrestrial deposits range from 1% to 5% total rare earths for solid rocks, 0.5% for placers, and 0.05% for ion adsorption clays (Elsner et al., 2025). Due to their chemical and mineralogical composition, marine deposits can best be compared to rare-earth-rich clays on land. In addition to the total rare earth content and the proportions of the technologically important rare earths neodymium, praseodymium, dysprosium, and terbium, a number of other factors are important for the mineability of a deposit. These factors include the size of a deposit, its geological structure and depth underground, the processability of the ores, and, last but not least, the market prices. In terrestrial deposits usually only the so-called light rare earths (including neodymium) are enriched in significant quantities. Heavy rare earths, which include dysprosium and terbium, occur on land only in clay deposits in quantities that are worth mining. In con-

Figure 1: Examples of ferromanganese crusts (A, B) and phosphorites (C, D) from the seafloor. Source: A, B: BGR, C: Hein et al. (2016), D: Kudrass et al. (2017).

trast, marine deposits often contain high proportions of heavy rare earths.

Ferromanganese crusts occur as 3—15 cm thick coatings on solid rock outcrops on the flanks and the summit areas of seamounts (Figure 1). Several thousand seamounts are rising more than 100 m above their surrounding seafloor in the Pacific Ocean alone (Gevorgian et al., 2023) representing a large area of potential ferromanganese crust deposits (Figure 2). Phosphorites also occur on seamounts, where phosphorus-rich minerals cement rock fragments and sediments into indurated rocks or form nodule-like fragments in the sediment (Figure 1). The unconsolidated rare-earth-rich deep-sea mud covers large areas of the seabed (several hundred square kilometers) in the abyssal plains beyond a depth of 4,000 meters. They form 10—20 m thick layers in the sediment, which either outcrop directly on the seafloor or lie under a meters-thick sediment layer (Takaya et al., 2018; Kato et al., 2011).

In manganese nodules and massive sulfides, on the other hand, the content of rare earths is rather low and not viable for economic mining with current technology.
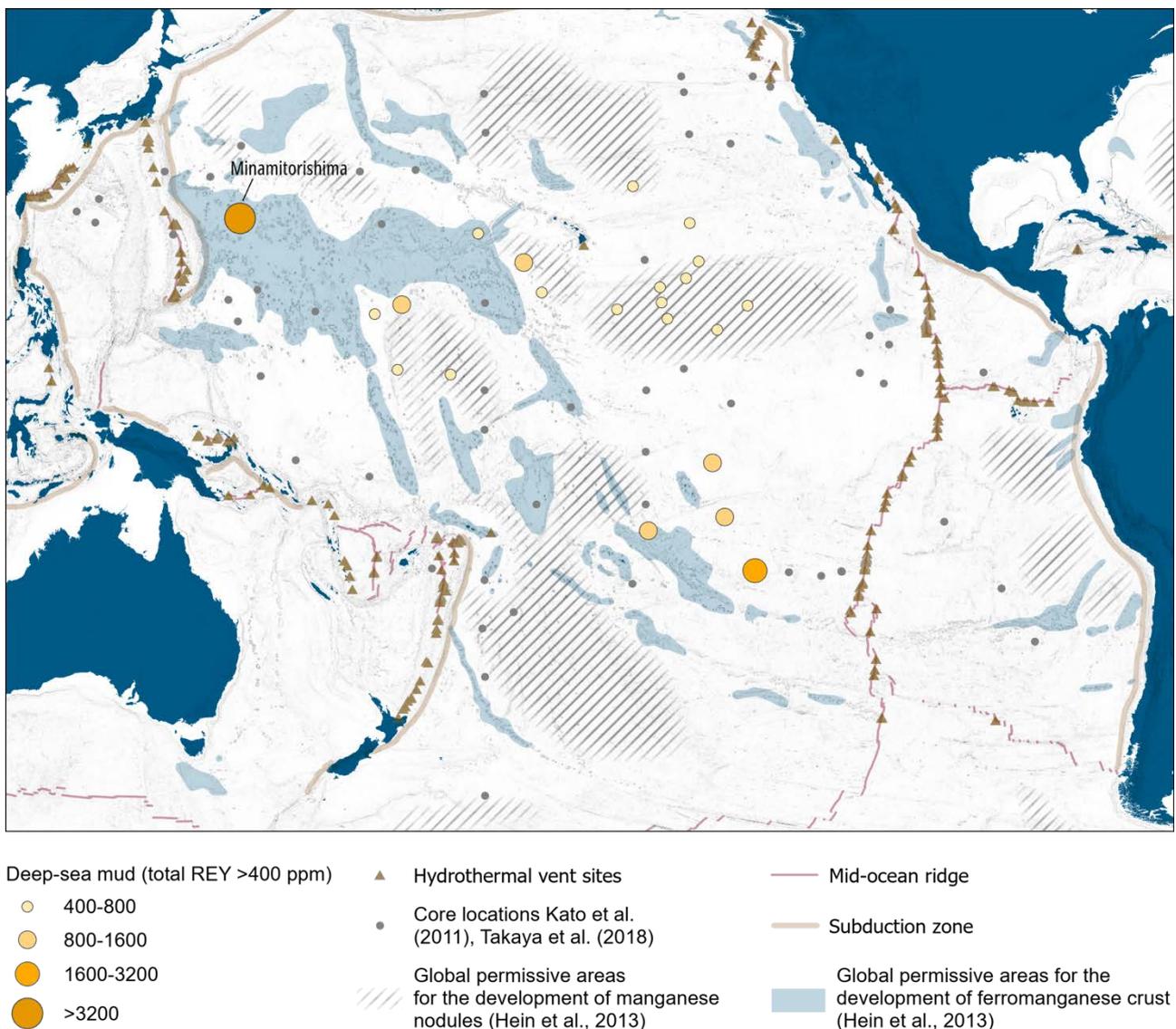

Deep-sea mud (total REY >400 ppm)
- ○ 400-800
- ○ 800-1600
- ○ 1600-3200
- ○ >3200

▲ Hydrothermal vent sites

● Core locations Kato et al. (2011), Takaya et al. (2018)

▨ Global permissive areas for the development of manganese nodules (Hein et al., 2013)

— Mid-ocean ridge

— Subduction zone

▬ Global permissive areas for the development of ferromanganese crust (Hein et al., 2013)

Figure 2: Map of the Pacific Ocean showing permissive areas for ferromanganese crust development, rare-earths-rich deep-sea mud (detected in drill cores as rare-earth elements including yttrium — SEY) and manganese nodules that could be of interest for deep-sea mining. Massive sulfides at known hydrothermal fields are also shown. Figure: Anna Krätschell/ MMR/ GEOMAR.

3. Mining, environment, and economics

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has begun test mining of rare-earth-rich deep-sea sediments near Minamitorishima Island in the western Pacific in early 2026 (Figure 2). Reserves in this area are estimated at 1.2 million tons of rare-earth oxides, which could cover the current global demand for terbium for 32 years and for dysprosium for 56 years (Takaya et al., 2018). For recovery, the deep-sea mud will be fluidized in-situ and pumped to a surface vessel where the rare-earth-rich mineral fraction will be mechanically enriched and finally processed using hydrometallurgical methods.

JAMSTEC is also a pioneer in ferromanganese crust development and has already tested mining technology that has extracted 649 kilograms of crust material from a seamount in the western Pacific (Roland Berger, 2025). German scientists carry out studies on ferromanganese crusts in the central eastern Atlantic and off the coast of New Zealand. The economic potential of ferromanganese crusts can already be quite high on individual seamounts if they form guyots, i.e. table mountains with a large summit area, with a regular crust coverage. For example, the crust resource on a group of seven seamounts in the eastern Atlantic was estimated at approximately 100 million tons containing 290,000 tons of rare earths (Torres-Rodriguez et al., 2026). At a current consumption rate of 5,000 tons per year, German industry could be supplied with rare earths for over 58 years.

While a processing method already exists for deep-sea mud, this does not yet apply for extracting rare earths from ferromanganese crusts. Due to their binding forms in ferromanganese crusts, similar hydrometallurgical processes to those used for deep-sea mud could be applied. Initial studies in this direction have already been conducted (Hein et al., 2016; BGR data), but their economic viability cannot be assessed yet. However, ferromanganese crusts contain additional elements required for high technology in economically relevant quantities such as cobalt, tellurium, scandium, and platinum. Moreover, ferromanganese crusts from the seafloor contain only very low concentrations of radioactive elements such as uranium and thorium, which must be separated and disposed of at great expense during the processing of ores from land deposits.

Environmental impacts are coming into focus with regard to possible future mining of ferromanganese crusts. For example, seamounts are considered extremely vulnerable ecosystems (Walling & Auster, 2017). They are almost always of volcanic origin and rise individually or in chains up to some thousand meters above the surrounding abyssal plains. Seamounts form barriers to water currents and create turbulence leading to a significant increase in food supply. Rocky slopes or slopes covered with ferromanganese crusts provide ground for habitat-structuring organisms such as deep-sea corals and sponges, which in turn create diverse habitats for other species (Morgan et al., 2015, Shen et al., 2021). For these reasons, seamounts are hotspots of biological production and biodiversity, with a multitude of species that cannot exist in the surrounding abyssal plains. If seamounts are geographically, hydrologically, and topographically isolated, they very likely form centers of genetic isolation, and it is assumed that such isolated seamount ecosystems exhibit endemisms, i.e., species that occur exclusively at single locations (Rogers, 2018; Saito et al., 2025). The extent to which populations of adjacent seamounts are genetically interconnected and how current environmental conditions influence this connectivity is the subject of intensive research.

4. Concluding remarks

The International Seabed Authority, based in Jamaica, is currently developing regulations for the exploitation of marine mineral resources in international waters, which also include the resources mentioned here. In addition to the existing regulations on the exploration of these raw materials, this will provide binding legal provisions for possible deep-sea mining. This could also enable Germany and other European countries to diversify their supply of critical and strategically important raw materials through deep-sea mining.

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